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EFFECT OF WASTE DISCHARGE ON THE WATER QUALITY OF NIPIGON BAY, LAKE SUPERIOR, 1983

October, 1986

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Ontario

Ministry
of the
Environment

J. BISHOP, Director
Water Resources Branch

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EFFECT OF WASTE DISCHARGES ON THE WATER QUALITY OF NIPIGON BAY, LAKE SUPERIOR, 1983

M.K. Kirby
Great Lakes Section
Water Resources Branch
Ontario Ministry of the Environment

October 1986

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FOREWORD

The information presented in this report was derived from one of a series of investigations conducted by the Ministry under the 1983 Lake Superior Intensive Year program, as a contribution to the International Joint Commission's Great Lakes International Surveillance Plan.

The 1983 survey was conducted to update information collected in 1974 on conventional water quality parameters and to provide baseline information concerning the identity and concentration of organic pollutants in pulp and paper discharges.

While publication of the report has been delayed, improved treatment technology at the Nipigon mill since 1983 has been directed mainly towards reducing air emissions. The quality of the effluents and the receiving water as described in this report are unlikely to have changed significantly since that time.

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ACKNOWLEDGEMENTS

This study was initiated and designed by Ms. C. Cherwinsky of the Great Lakes Section, Ontario Ministry of the Environment under the supervision of Dr. M.A. Zarull of the same Section. This study was funded in part by Environment Canada under the terms of the Canada-Ontario Agreement on Great Lakes Water Quality.

1. EXECUTIVE SUMMARY

In 1983 the Ontario Ministry of the Environment conducted a water quality survey of Nipigon Bay on Lake Superior. Nipigon Bay is the receiving water of discharges from the Red Rock Water Pollution Control Plant (WPCP) and Domtar Packaging Limited, a pulp and paper mill. Wastes from both sources are discharged into a canal which empties the combined effluent into Nipigon Bay at Red Rock. Municipal wastes from the Nipigon WPCP are discharged indirectly into the Bay via the Nipigon River. Studies of the area conducted in 1969 and 1974 had identified problems with odour in the surface water, tainting of fish flesh and alterations in benthic community structure in which indigenous bottom fauna were replaced by pollution tolerant forms. Since the early studies were conducted, improvements were made in the operating and waste treatment procedures at the mill and in the waste treatment at the Red Rock WPCP. These changes suggested a need for re-evaluating the water quality of the Bay. The specific objectives of the 1983 survey were to update information collected in 1974 on the concentration of conventional water quality parameters and to provide baseline data concerning the identity and concentration of organic pollutants characteristic of the pulp and paper industry for which there was meagre historical information.

An analysis of flows and concentrations of conventional parameters in the Red Rock WPCP discharge and in the combined mill and WPCP discharge suggested that most of the loadings to Nipigon Bay were attributable to the mill. The water quality of Nipigon Bay as indicated by conventional parameters has improved substantially since the previous survey conducted in 1974. The improvement in water quality is consistent with the changes in operating and waste treatment procedures that were incorporated in the mill between 1974 and 1983. These changes were designed to reduce losses of volatile odourous materials from the stacks and reduce losses of suspended solids and the toxicity of the effluent.

Despite the changes and improvements in conventional parameters, violations of the Provincial Water Quality Objectives (PWQO) for the protection of aquatic life and recreation in and on water for phenols, total coliforms and several metals (cadmium, copper, iron, mercury and zinc) were observed at one or more sampling locations in the bay in 1983. Of the metals, iron and zinc exceeded the PWQO only in the immediate vicinity of the outfall. The mill is the major source of both metals, but the WPCP is also a contributor.

Cadmium violations occurred over a larger area than the iron and zinc violations with inputs attributable to both the mill and WPCP. Copper levels exceeded the PWQO at almost all locations where it was sampled, including stations in the east side of the bay, outside the influence of the effluent plume. Although the mill is a source of copper, the occurrence of violations at sampling locations outside the influence of the plume suggests that background concentrations are high. Mercury exceeded the PWQO at only one location on the Nipigon River and was detected at a few locations downstream of this location. The violation is not thought to be environmentally significant. The high value may be the result of laboratory error. There are no known uses of mercury in the area.

Most of the violations of the PWQO for total coliforms occurred within 1.3 km of the combined mill and WPCP outfall. Violations were noted at three other locations outside this area, up to 6 km from the outfall. The mill is the main source of the total coliforms since the concentration of these bacteria in the combined effluent averaged eleven times that of the WPCP effluent alone for the period July 18-20, 1983. The analytical test for total coliforms is sensitive to the presence of disease-causing organisms or their indicators, as well as bacteria of no known pathogenic significance. Consequently, the numbers of total coliforms are not directly related to the health risks associated with contact with the contaminated water. To assist in the interpretation of the total coliform results, some samples were analyzed for fecal coliforms. The results of these tests indicated that the violations of the PWQO are not due to fecal contamination. However, since all the species of bacteria detected by the total coliforms test were not identified during the survey, the potential health risks arising from recreational uses of Nipigon Bay could not be assessed.

The concentrations of reactive phenols exceeded the PWQO for the protection of aquatic life over a large area, including stations up to a maximum distance of 3.9 km from the outfall. The phenol objective was exceeded twice at the water treatment plant intake for the Town of Red Rock where the maximum concentration was 6 ug/L.

The Ontario Drinking Water Objective which was set primarily to prevent the occurrence of undesirable tastes and odours was also exceeded once at the water treatment plant intake for the Town of Red Rock. Periodic complaints of taste and odour in the drinking water have been received from residents of the Town of Red Rock. High phenol concentrations in raw water may contribute to taste and odour problems in finished water, since phenol compounds may only be partially removed during the water treatment process. Some chlorinated phenols have taste and odour thresholds as low as 0.1 ug/L. The Domtar mill is a source of phenolic compounds. Another potential source is the sunken logs in the area of the intake.

The results of the reactive phenolics test are not directly interpretable in terms of toxicity or organoleptic properties since the test is sensitive to the presence of a variety of different phenolic compounds. To assist in the interpretation of the test, analyses were performed to determine the concentrations of a number of substituted phenols and chlorophenols. Of these, guaiacol was detected near the outfall at concentrations which have been shown in laboratory studies to taint fish flesh and cause odour problems in water.

Other organics of concern were the resin acids, isopimaric and abietic acid, which were detected in the combined effluent at concentrations which exceeded LC50 values cited in the literature as toxic to coho salmon and/or trout, suggesting a potential problem with fish toxicity.

A fish bioassay was conducted by the Toxicity Unit of the Ministry of the Environment concurrently with the water quality survey. All the effluent samples, except one, met the Federal requirements of at least 80% survival of fish in 65% effluent concentration at the end of a 96-hour exposure period.

The violations of the Provincial Water Quality Objectives and the detection of organics at levels which taint fish flesh, cause odour problems in water, and are toxic to fish, suggest a need for further improvements in the 1983 effluent quality. Additional steps have been taken at the mill since 1983 to reduce contaminant discharges, but these have been directed towards improving the quality of stack emissions and are unlikely to have changed the quality of the effluent or receiving water.

RECOMMENDATIONS

1. Steps should be taken to reduce the concentration of phenolic compounds in the vicinity of the water intake for the Town of Red Rock where reactive phenolics exceeded the Provincial Water Quality Objective for the protection of aquatic life and the Ontario Drinking Water Objective which was set primarily to prevent the occurrence of undesirable tastes and odours.

2. The species detected in the total coliform test should be identified to enable an assessment of the health risks associated with the violations of the PWQO found at most of the sampling stations near the combined mill and WPCP outfall.

3. Provincial Water Quality Objectives should be established for guaiacol, isopimaric acid and abietic acid which are common in pulp and paper mill effluents and which were detected during this survey at levels which have been found to be toxic to fish in laboratory studies or cause taste and odour problems in water.

4. Research should be conducted on the organic compounds detected in this study in the combined discharge and receiving water for which little is known of the ecological and/or toxicological significance. Included among these are phenolics, fatty and resin acids and aromatic acids (see Table 5 of this report).

3. INTRODUCTION

In 1983 the Ontario Ministry of the Environment conducted a survey of the water quality in Nipigon Bay on Lake Superior. There were two main objectives of the survey; the first of which was to update information collected in 1974 concerning the extent of water quality impairment in the bay resulting from waste water discharges from Domtar Packaging Limited, a pulp and paper mill (Polak 1975 a and b). Early studies of the area had identified problems with odour in the surface water, tainting of fish flesh and alterations in benthic community structure in which indigenous bottom fauna were replaced by pollution tolerant forms (German 1968, Kelso et al 1977). Since these early studies were conducted, several operational and waste treatment procedures in the mill were changed to improve effluent quality. An improvement in effluent quality was anticipated to reduce the concentration of some parameters in the receiving water. However, it could not be presupposed that the concentration of all parameters would be reduced. Some could be expected to increase or remain unchanged as a result of their persistent and cumulative nature.

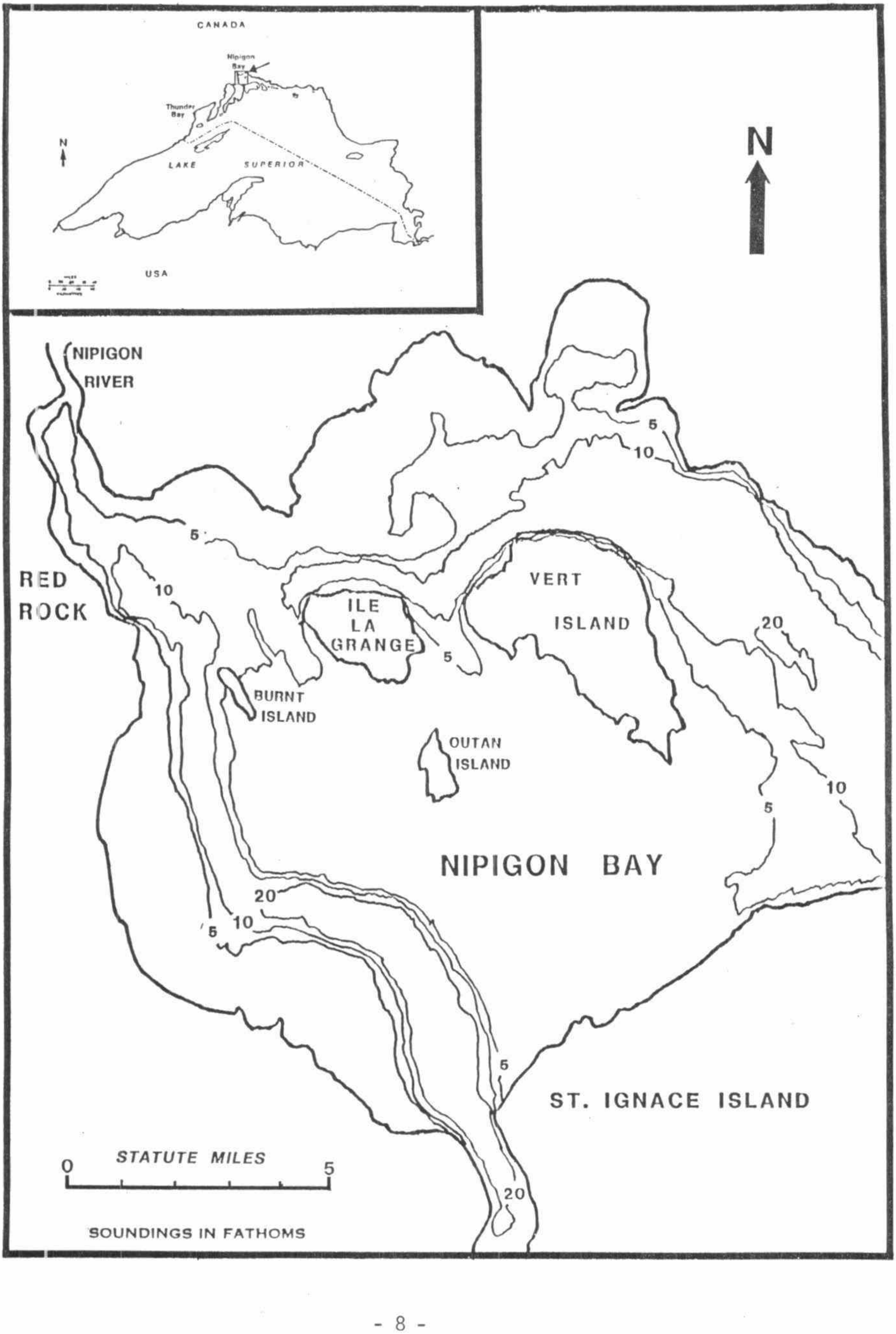
The second objective of the study was to provide baseline information concerning the identity and concentration of organic pollutants in the waste and receiving waters for which historical information was limited or non-existent. Included among these pollutants are pesticides, phenols, chlorinated organics and resin and fatty acids. Their identification and measurement is important since some of the potential contaminants have been identified as carcinogens and mutagens (Nestmann et al 1980, Kringstad and Linstrom 1984), while others have been shown to taint fish flesh (Shumway and Palensky 1973) and cause taste and odour problems in drinking water.

4. STUDY AREA DESCRIPTION

Nipigon Bay is located on Lake Superior, east of Thunder Bay It is fed primarily by the Nipigon River which has a mean annual flow of 365 m^3/s (Kelso et al 1977). Upon entering the bay, flow from the river is directed along two primary channels, one running south past the Domtar Mill to Nipigon Strait and the other running parallel to the north shore of the bay (Figure 1).

The major consumers of water from Nipigon Bay are the Improvement District of Red Rock and Domtar Packaging Limited. These respectively use averages of 1000 and 95000 m^3 of water/day (Ontario Ministry of the Environment draft). Commercial fishing for walleye thrived in the area prior to the early 1960's, but is currently insignificant. The first Ministry of the Environment water quality investigation was initiated in 1966 in response to the loss of commercial fishing which was attributed to declines in the number of walleye and in the palatability and marketability of the fish (German 1968). Sport fishing similarly declined in the 1960's, but is currently undergoing a revival, which is due, in part, to walleye stocking by the Ontario Ministry of Natural Resources. Other important sport fish in Nipigon Bay are lake trout and perch (J. Vander Wal, MOE, Northwestern Region, pers. comm.)

Contributors to the pollutant loading of Nipigon Bay include the Nipigon Water Pollution Control Plant, the Improvement District of Red Rock Water Pollution Control Plant and the Domtar Packaging Limited mill. The Nipigon Water Pollution Control Plant services a population of 2180 and discharges sanitary wastes into the Nipigon River following primary treatment. Average flow from the plant in 1983 was 1359 m^3/day. Average BOD, suspended solids and total phosphorus concentrations in the effluent were 28.6, 36.6 and 3.0 mg/L, respectively (Archer 1984).


CANADA
Nipigon Bay
Thunder Bay
N
LAKE SUPERIOR
USA
N
NIPIGON RIVER
RED ROCK
ILE LA GRANGE
VERT ISLAND
BURNT ISLAND
OUTAN ISLAND
NIPIGON BAY
ST. IGNACE ISLAND
5
10
20
STATUTE MILES
0
5
SOUNDINGS IN FATHOMS

Wastes from both the Improvement District of Red Rock Water Pollution Control Plant and from the Domtar Packaging Mill are discharged into a canal which empties into Nipigon Bay at Red Rock. The Water Pollution Control Plant services a population of 1138. It currently employs primary treatment before waste discharge, but at the time of the 1974 study, the wastes were untreated. In 1983 the average flow was 1273 m^3/day. The average concentrations of BOD, suspended solids and total phosphorus were 32.0, 27.0 and 2.9 mg/L, respectively (Archer 1984). Effluent flows from the Domtar Packaging Mill greatly exceed those from either the Nipigon or Red Rock Water Pollution Control Plants. An average of 93,000 m^3 of process waste water was discharged daily from the Domtar mill into the canal in 1983. Average loads of BOD, suspended solids and total phosphorus were 16,500, 4,950 and 24.9 kg/day, respectively, in 1983. The BOD and phosphorus loads were below the limits of 22,000 and 93.3 kg/day set by the Ontario Ministry of the Environment, while suspended solids marginally exceeded the limit of 4,800 kg/day (Ontario Ministry of the Environment 1983).

The Domtar mill uses groundwood and kraft pulping processes in the manufacture of kraft linerboard and newsprint. The mill has a bleachery. Pollution abatement facilities in place at the time of the 1974 study included a causticising plant and lime kiln, which reduce losses of calcium carbonate; a primary clarifier, which removes suspended solids from the effluent and a turpentine recovery system (Kelso et al 1977, Whittle and Flood 1977). Facilities installed in between 1974 and 1983 include a condensate steam stripper, which reduces losses of volatile (primarily sulphurous) odorous and toxic materials; a classifier, which removes grit in the woodroom and reduces losses of suspended solids; and alum treatment of the woodroom effluent, which reduces toxicity of the effluent through the removal of resin and fatty acids.

The Control Order in place for Domtar in 1983 expired in 1985 and a new one is under review. Effluent requirements include limiting the loads for suspended solids and BOD to 5.5 metric tons/day (MT/day) and 23 MT/d, respectively, based on a production of 800 MT/day. In addition, the effluent must meet federal guidelines in a fish toxicity test of at least 80% survival of fish exposed to 65% effluent (Environment Canada 1972). (A. Zorzes, MOE, Northwestern Region, pers. comm.).

5. SURVEY DESIGN AND LABORATORY METHODS

In order to characterize the discharges, samples of the mill intake water, the Red Rock Water Pollution Control Plant effluent and the combined mill and Water Pollution Control Plant (WPCP) effluent were collected daily for five days beginning July 18, 1983. It was not possible to sample the mill effluent alone, as it is discharged as three separate streams, one of which enters the canal upstream of the Water Pollution Control Plant effluent and the other two, downstream. Sampling locations in Nipigon Bay and its vicinity fell into two groups. The first group consisted of 10 sites (stations 856, 888-896) located within 1000 m of the combined mill and WPCP outfall, and one site on the Nipigon River (887) (Figure 2). These stations were generally sampled daily for 5 days beginning July 18 to provide ancillary information for a concurrent fish toxicity study conducted by the Northwestern Region and the Toxicity Unit of the Ontario Ministry of the Environment. The purpose of the toxicity study was to determine whether the effluent met with federal guidelines of at least 80% survival of rainbow trout exposed to 65% effluent using a standard laboratory procedure (Environment Canada 1972). In addition, an "in situ" bioassay was performed to compare field results with those obtained from the standard laboratory test (Flood et al draft).

The second group consisted of the remaining locations which covered an area from the immediate vicinity of the outfall to over 20 km away. These stations were generally sampled daily over a 3-day period beginning July 19, 1983 and were selected to provide information on the extent of water quality impairment in the bay. Included in this group were stations which would aid in identifying sources of pollutants other than the mill and stations which would aid in determining the significance and impact of the measured concentrations. For example, station 850 was used to measure contaminants from sources along the Nipigon River (e.g. the Nipigon WPCP), while station 851 at the Red Rock water treatment plant intake was used to ascertain the effects of the Nipigon River and the combined mill and WPCP discharge on the Town's raw water supply. Information about the direction of the effluent plume dispersal was obtained from stations located along

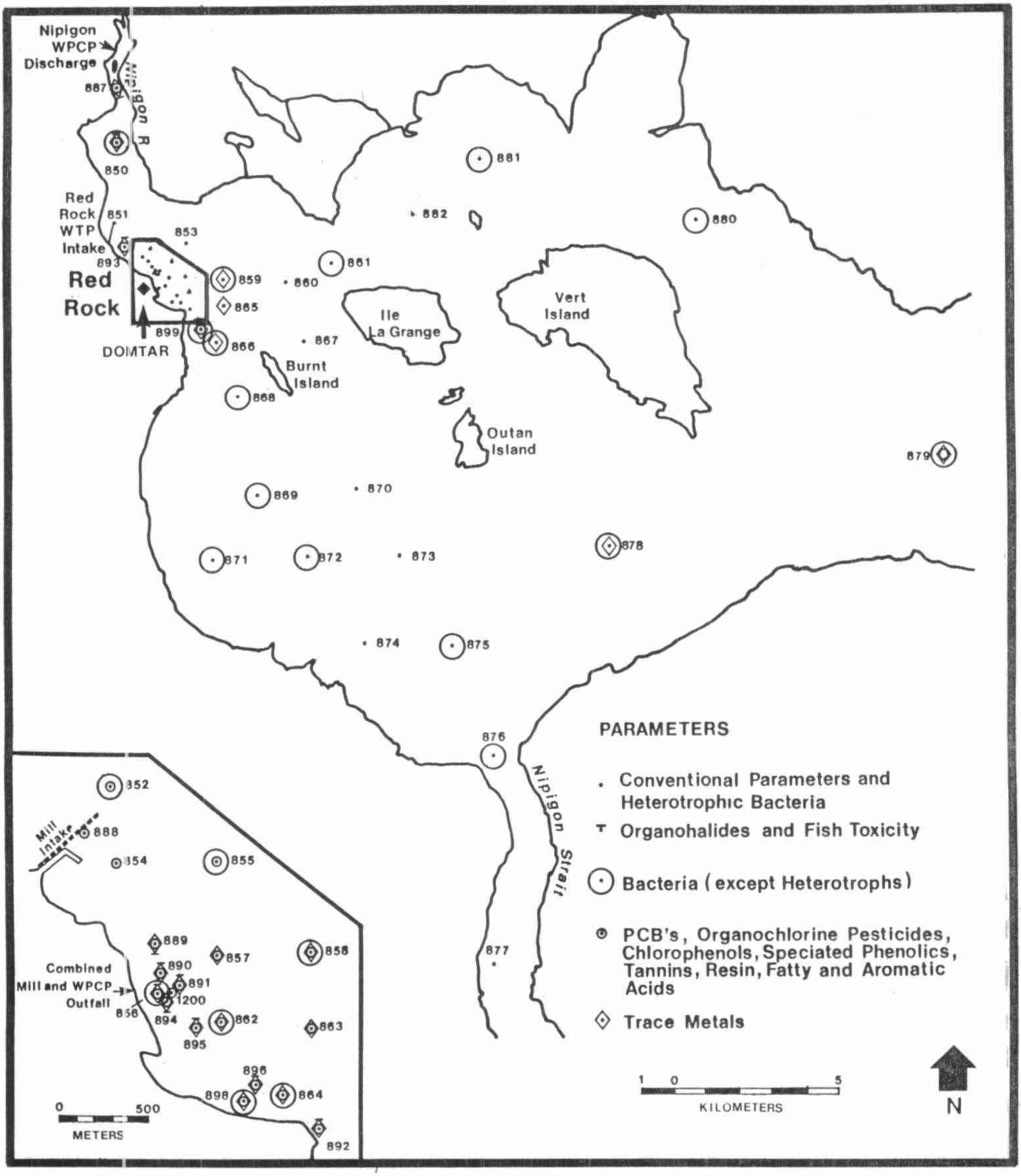


Figure 2 : Map of the Sampling Locations

the two channels which govern flow patterns within the bay. Station 879 in the east portion of the Bay was initially selected to provide information on background conditions since it was outside the influence of the plume in previous studies. However, caution must be exercised in using this location as a control. Due to factors such as differences in the morphometry and sediments of the eastern and western portions of the bay, major differences may exist between station 879 and stations in the vicinity of the plume independent of the point source impacts (J. Vander Wal, MOE, Northwestern Region, pers. comm.).

The parameters selected for measurement included both conventional water quality parameters such as total phosphorus and dissolved oxygen, bacteria, and pollutants characteristic of the pulp and paper industry such as resin and fatty acids (Appendix 1). The conventional water quality parameters were measured at all locations and organohalides, at the fish toxicity sampling locations. Sampling for trace metals, polychlorinated biphenyls (PCB's), organochlorine pesticides, chlorophenols, speciated phenolics, tannins, and resin, aromatic and fatty acids was restricted to locations within 2 km of the outfall, the Nipigon River and station 879. Bacteria were enumerated at stations up to 17 km from the outfall. The wide range used for bacterial sampling is based on the results of a previous Nipigon study which showed that the area of the bay affected by the discharge was substantially greater when delimited by bacterial indicators as compared to chemical indicators (Rokosh et al 1977).

All samples were collected at a depth of 0.5 m since the plume is concentrated largely within the top metre of the water column (Fox 1977). All laboratory analyses were performed by the Ministry's laboratories in Thunder Bay and Toronto according to the methods described in Outlines of Analytical Methods (Ontario Ministry of the Environment 1981) and in Adamek and Au (1979).

6. RESULTS AND DISCUSSION

Effluent Characterization

Mill production and effluent data are given in Table 1 for the five days of the survey, for the month of July 1983, and for the year 1983. These data suggest that the mill was operating at or above average capacity during the survey period.

Data on the average concentration of conventional parameters and bacteria in water samples collected from July 18 - 20 at the Domtar mill intake, at the Red Rock WPCP discharge and in the canal (combined WPCP and mill discharge), are shown in Table 2. The averages are geometric means since water quality data are usually lognormally distributed.

Of the 30 conventional and bacterial parameters listed in Table 2, 12 are on average more concentrated in the discharge from the WPCP than in the combined WPCP and mill discharge. Three of these (total phosphorus, ammonia and Escherichia coli) differ by a factor of greater than 10. While this might suggest that the WPCP contributes substantially to the pollutant loading of some parameters in Nipigon Bay, the average daily flow from the mill in 1983 was 73 times greater than that of the WPCP. This indicates that the loading from the WPCP would equal that from the mill if the concentration of a parameter in WPCP effluent were 74 times that of the combined WPCP and mill effluent. No parameter met with this criterion. However, the ammonia concentration in the WPCP effluent exceeded that in the combined effluent by a factor of 54. Therefore, for all parameters, except ammonia, the major portion of the loadings to Nipigon Bay from the combined discharge are attributable to mill wastes.

All parameters, except pH, are elevated to some degree in the combined discharge relative to the mill intake. The greatest increases are for reactive phenolics, sulphate reducers, heterotrophic bacteria and fecal coliforms. The elevation in fecal coliforms likely reflects the presence of Klebsiella pneumoniae, a bacterial species associated with water high in organic matter and common in pulp and paper mill effluents.

TABLE 1

MILL PRODUCTION AND EFFLUENT DATA

DOMTAR PACKAGING LTD., RED ROCK

Date	Saleable Production (Tonnes/Day)		Total	Suspended Solids (Tonnes/Day)	BOD_5 (Tonnes/Day)	Phenolics (Kg/Day)	Flow ($x10^3m^3/d$)
	Linerboard	Newsprint					
July 17/83 (Day 1)	653	206	859	5.0	16.6	347	103.6
July 18/83 (Day 2)	582	192	774	4.6	11.8	293	98.4
July 19/83* (Day 3)	512	136	648	5.0	16.2	308	101.9
July 20/83 (Day 4)	511	197	708	5.4	17.9	230	97.4
July 21/83 (Day 5)	448	192	640	4.9	18.9	280	92.3
July 1983 (Monthly Mean)	507	164	671	5.1	17.7	-	96.2
(Monthly Low)	123	21	175	3.4	11.5	-	40.9
(Monthly High)	743	217	926	9.4	24.9	-	106.6
1983 (Yearly Mean)	-	-	659	4.95	16.6	-	93.1

*Began digesting hardwood for 25% of total pulp production.

TABLE 2

Geometric Mean Concentrations of Conventional Parameters in Water Samples Collected at the Domtar Mill Intake, at the Red Rock Pollution Control Plant (WPCP) Discharge, and in the Canal (Combined WPCP and Mill Discharge)

Parameter	Mill Intake	WPCP Discharge	Combined WPCP & Mill Discharge
DOC (mg/l)	3.6	14.3	58.6
Tannins (mg/L)	0.0	3.6	53.1
Sulphate (mg/L)	3.0	48.9	123.1
Reactive Phenolics (ug/L)	0.4	8.4	2769.4
*BOD (mg/L)	0.8	30.9	111.8
Total Solids (mg/L)	97.8	378.8	539.4
*Suspended Solids (mg/L)	2.6	41.0	79.6
Dissolved Solids (mg/L)	94.5	336.3	459.2
COD (mg/L)	8.8	132.2	395.4
Colour (Hazen units)	13.5	50.3	283.4
Conductivity (microsiemens/cm)	120.0	520.8	492.4
Turbidity (Formazin units)	2.8	25.7	50.6
*Total Phosphorus (mg/L)	0.01	3.1	0.26
TKN (mg/L)	0.2	17.9	1.83
Chloride (mg/L)	1.3	29.8	25.6
Sodium (mg/L)	1.4	35.5	82.4
pH	7.8	7.1	6.9
Ammonia (mg/L)	0.01	12.6	0.23
Aluminum (mg/L)	0.1260	0.3684	3.6616
Copper (mg/L)	0.0055	0.0546	0.0135
Iron (mg/L)	0.1530	1.0472	0.4765
Zinc (mg/L)	0.0106	0.0576	0.0266
Sulphide (as H_2S, mg/L)	1.00	11.6	22.4
Total Coliforms (counts/100 ml)	219	68043	215367
Fecal Coliforms (counts/100 ml)	4.0	9460	2183
Fecal *Streptococci* (counts/100 ml)	4.0	691	191
Heterotrophs (counts/100 ml)	2424	320745	7234704
Pseudomonas aeruginosa (counts/100 ml)	2.0	519	100
Escherichia coli (counts/100 ml)	8.0	5242	200
Sulphate Reducers (counts/100 ml)	71.7	1878	482772

*Parameters monitored for compliance in the mill and combined mill and WPCP discharges.

Receiving Water Characteristics

a) Conventional Parameters

The concentrations of reactive phenols, cadmium, copper, iron, mercury and zinc exceeded the Provincial Water Quality Objectives for the protection of aquatic life at one or more locations on at least one sampling occasion.

Phenol violations occurred over a large area, including stations up to a maximum distance of 3.9 km from the outfall (Figure 3). The phenol objective was exceeded twice at the water treatment plant intake for the Town of Red Rock. The Ontario Drinking Water Objective (0.2 ug/L), which was set primarily to prevent the occurrence of undesirable taste and odours, was also exceeded once at this location. The maximum concentration at the intake was 6 ug/L. Periodic complaints of taste and odour in the drinking water have been received from residents of the Town of Red Rock. High phenol concentrations in raw water may contribute to taste and odour in finished water, since phenol compounds may only be partially removed during the water treatment process. Some chlorinated phenols have taste and odour thresholds as low as 0.1 ug/L (de Barros 1984). The mill discharges more phenols than the WPCP. Concentrations in combined effluent ranged from 2360 to 3020 ug/L over the days of the intensive survey, while those in the WPCP effluent ranged from 5.2 to 18 ug/L. Sunken logs are another potential source of phenols in the bay.

The phenol concentrations measured by the reactive phenolics test are not directly interpretable in terms of toxicity or organoleptic properties. The analytical technique is sensitive to varying degrees to the presence of phenol and various substituted phenolics (de Barros 1984). Consequently, two samples with the same concentration of reactive phenols may actually contain quite different compounds or quite different concentrations of the same compounds. Since individual phenolics can also vary greatly in their toxicity and ability to impart taste and odour to water and cause tainting of fish flesh, the samples can also potentially differ greatly in toxicity and organoleptic properties. In an attempt to increase the interpretability of the results, additional analyses for phenol, and a number of chlorophenols and other substituted phenols were performed on water samples from a few locations in Nipigon Bay. The results of these analyses are presented later in the report.

Copper levels exceeded the Provincial Objective (5 ug/L) at almost all locations where it was sampled, including stations 878 and 879 in the east portion of the bay (Figure 4). Although the mill is a source of copper, the occurrence of violations in the east portion of the bay suggests that background concentrations are high.

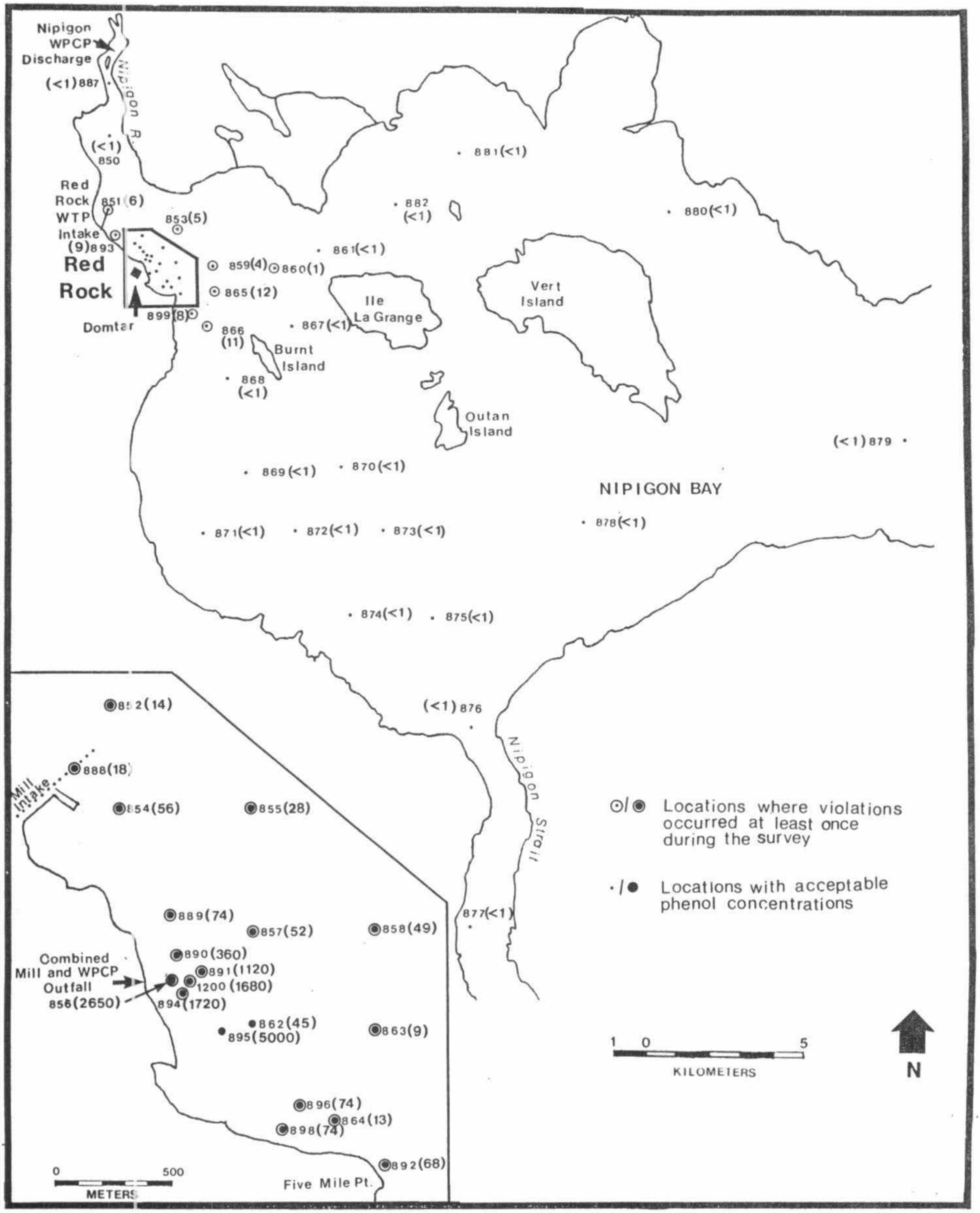


Figure 3. Violations of the Provincial Water Quality Objective for Phenol (>1 ug/L)
Numbers in brackets are the maximum concentrations (ug/L) from July 18-20,1983

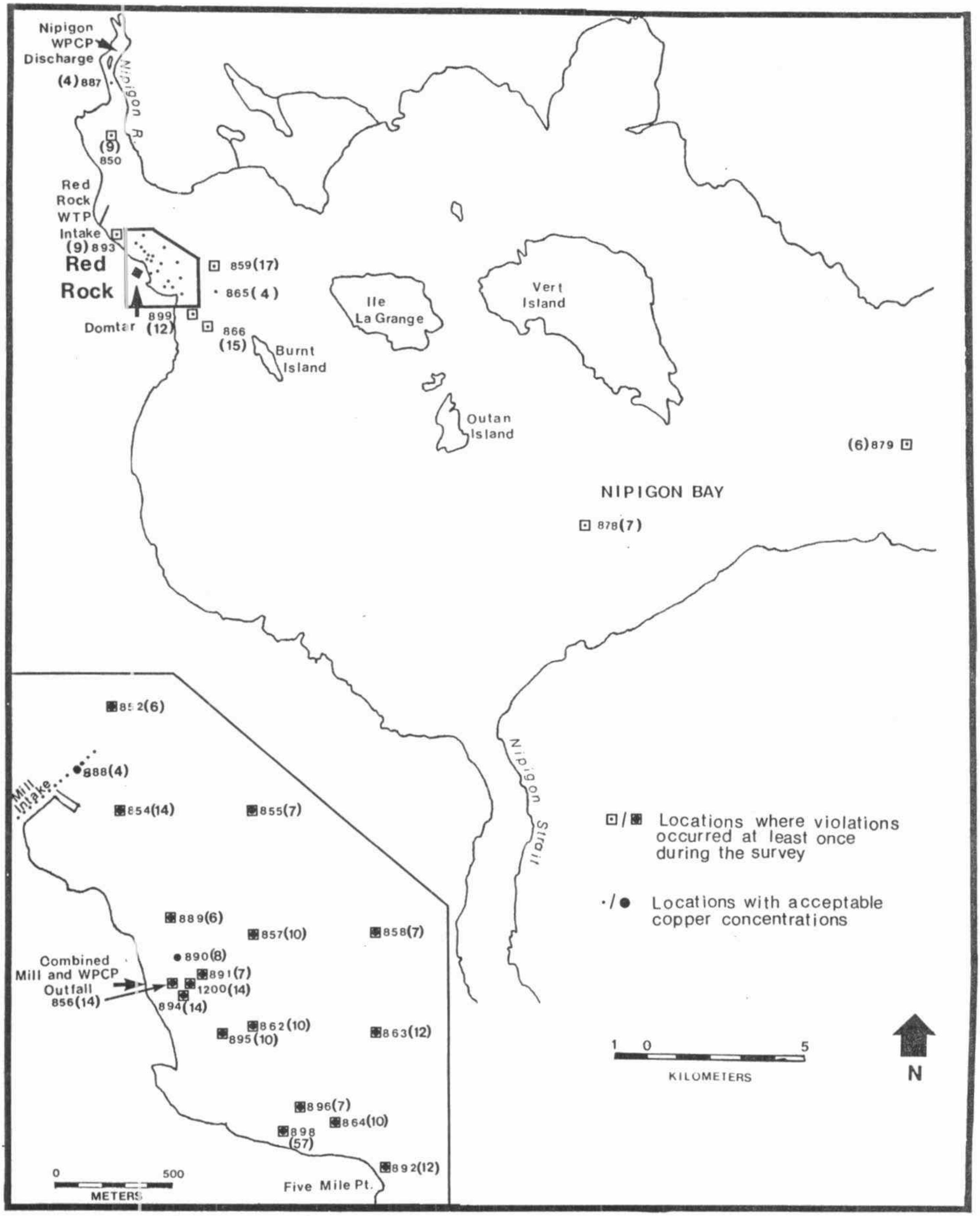


Figure 4. Violations of the Provincial Water Quality Objective for Copper (5 ug/L)
Numbers in brackets are the maximum concentrations (ug/L) from July 18-20,1983

Violations of the Provincial Water Quality Objective for cadmium (0.2 ug/L) occurred at a few stations in the immediate vicinity of the outfall, at station 892 at Five Mile Point and at station 879, in the east part of the bay (Figure 5). Concentrations of cadmium at the remaining locations were equal to or less than the detection limit (0.2 ug/L).

The Provincial Water Quality Objective for mercury (0.2 ug/L) was exceeded at station 850 in the Nipigon River where the concentration reached 0.36 ug/L (Figure 5). The concentration of mercury was less than the detection limit of 0.05 ug/L at all other locations except station 852 near the mill intake (0.05 ug/L), station 893 near the WTP intake (0.08 ug/L), station 856 in the receiving water near the combined mill and WPCP outfall (0.06 ug/L) and station 879 in the east part of the bay. The violation of the PWQO for mercury at station 850 is not thought to be environmentally significant. The high value may be the result of laboratory error. There are no known sources of mercury in the area.

The Provincial Water Quality Objective for zinc (30 ug/L) was exceeded at station 1200 near the outfall where the concentration reached 38 ug/L (Figure 6). The zinc concentrations in the WPCP and combined mill and WPCP effluents ranged from 54 to 60 ug/L and from 25 to 28 ug/L during the 3-day intensive survey, respectively, indicating that both the mill and the WPCP are sources of zinc. The larger flows from the mill suggest, however, that it is the main source.

Iron concentrations exceeded the Provincial Water Quality Objective (300 ug/L) at two locations near the combined mill and WPCP outfall (Figure 7). As with zinc, both the mill and the WPCP are sources, but the mill is the main source. The concentration ranges in the WPCP and the combined WPCP and mill effluent during the 3-day intensive survey were 870-1200 ug/L and 420-560 ug/L, respectively.

All 1974 sampling locations lie within a range of approximately 190 to 615 m of the outfall (Polak 1975a). Of the parameters which exceeded Provincial Water Quality Objectives in 1983, only phenol was measured in the 1974 samples. The current phenol objective (1 ug/L) was exceeded at all 1974 stations and at all 1983 stations within the same range of distances from the outfall.

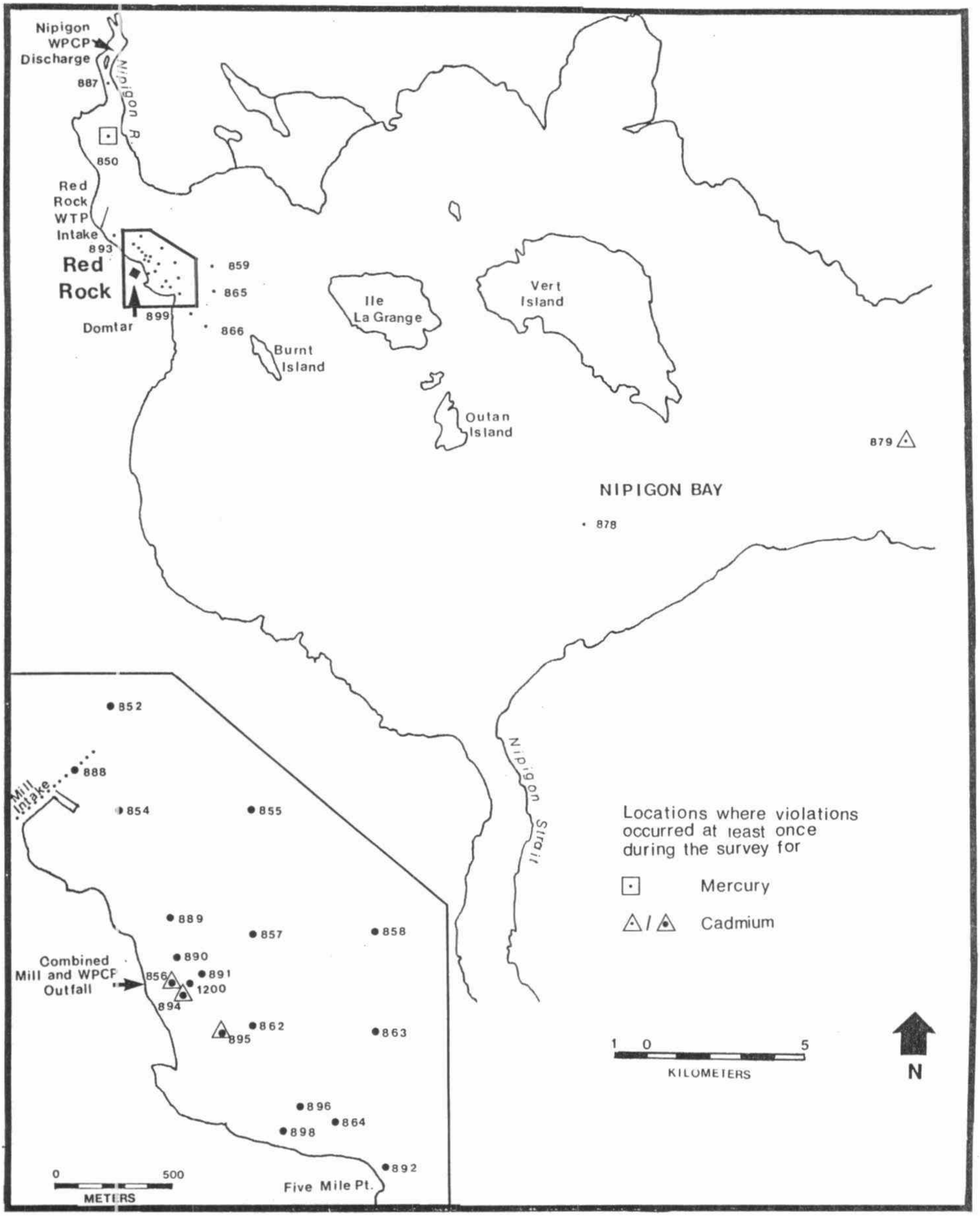


Figure 5. Violations of the Provincial Water Quality Objective for Mercury (0.2 ug/L) and Cadmium (0.2 ug/L)

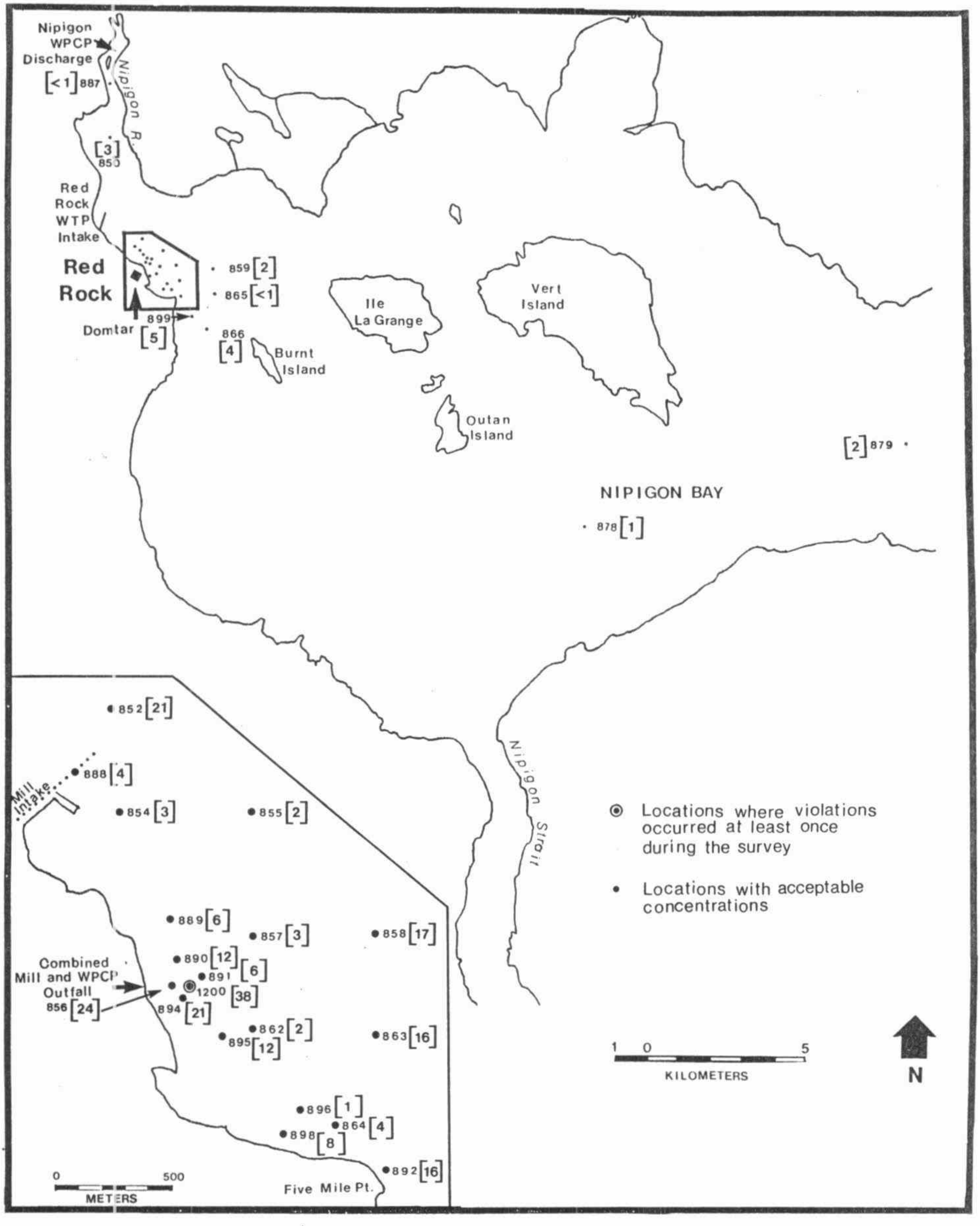


Figure 6. Violations of the Provincial Water Qualuty Objective for Zinc (30 ug/L)
Numbers in brackets are the maximum concentrations (ug/L) from July 18-20,1983

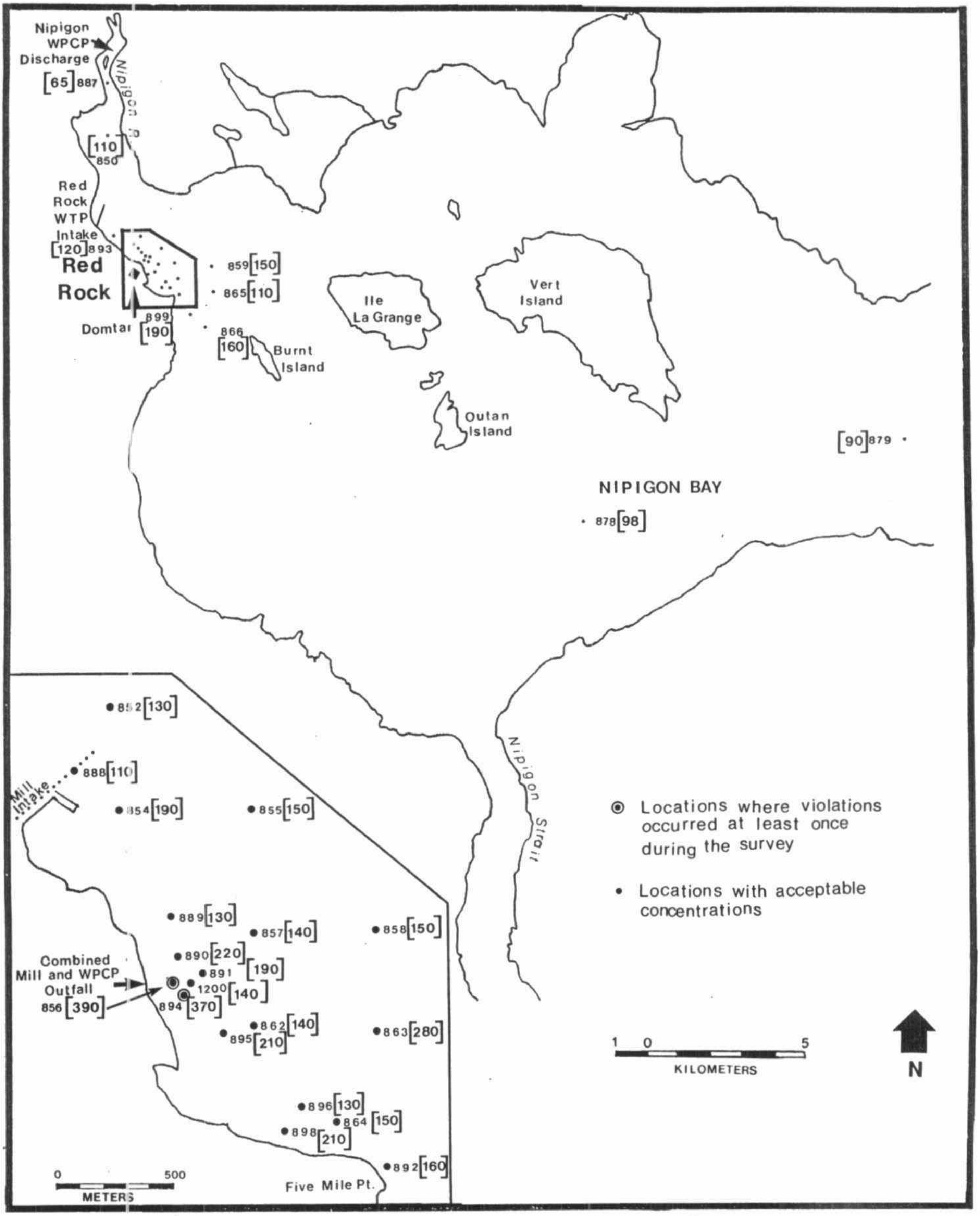


Figure 7. Violations of the Provincial Water Quality Objective for Iron (300 ug/L)
Numbers in brackets are the maximum concentrations (ug/L) from July 18-20,1983

b) Spatial-Temporal Patterns

The spatial-temporal relationships among selected conventional parameters were examined using principal components analysis. Principal components analysis is a multivariate summarization technique which can reduce the number of variables needed to describe the major spatial-temporal patterns in a data set, if the variables are correlated. Correlation among variables indicates that some of the information about the spatial-temporal variation of one variable is duplicated or described by that of another, correlated variable. Principal components analysis eliminates the redundancy due to correlations among variables and eliminates the need to examine the spatial temporal pattern of each variable separately. The technique identifies parameters with similar spatial-temporal patterns and represents the pattern by a new variable or component. More than one component is required if more than one major pattern exists in the data. The computational details of the technique are described in Tatsuoka (1971).

Input to the principal components analysis consisted of 76 samples representing locations for which information on the twenty parameters listed in Table 3 was complete for at least two of the three days of the survey. The parameters (except pH) were transformed to a logarithmic scale prior to the analysis. Values below the detection limit were set to half the detection limit. The analysis was done by computer using the SAS program FACTOR (SAS Institute Inc., 1982).

Two interpretable principal components were extracted which respectively accounted for 73% and 11.2% of the variance present in the original data. The efficiency of the summarization is illustrated by the fact that if one of the original parameters were used to describe the spatial-temporal patterns, only 5% of the total variance would be accounted for. The most similar parameters may be identified by examining the factor loadings on the two components. The factor loadings measure the correlation between the original parameters and the component scores and consequently range between -1 and +1.

TABLE 3

Factor Loadings of the Chemical and Physical Parameters on the First Two Principal Components

	Component 1	Component 2
BOD	0.98	-0.06
Total Solids	0.91	-0.08
Suspended Solids	0.92	0.00
Dissolved Solids	0.90	-0.09
COD	0.82	-0.03
Colour	0.98	-0.07
Conductivity	0.97	-0.12
Turbidity	0.96	0.01
Total Phosphorus	0.94	-0.11
TKN	0.95	-0.08
Chloride	0.98	-0.09
Sodium	0.98	-0.05
pH	-0.89	0.04
Temperature	0.82	-0.18
Dissolved Oxygen	-0.80	-0.05
Aluminum	0.72	0.57
Copper	0.08	0.83
Iron	0.22	0.90
Zinc	0.57	0.54
Hydrogen Sulphide	0.94	-0.12

Parameters with high positive loadings on the same component would behave similarly in time and space and would exhibit an inverse pattern to parameters with large negative loadings. There would be little similarity between parameters with near zero loadings and those with large positive or large negative loadings on a component. For example, similar spatial-temporal patterns would be exhibited by sodium and chloride which have correlations of .98 with the first component. The patterns apparent in pH with a correlation of -0.89 with the first component would also be similar, except that in areas where, or at times when, sodium and chloride are high, pH would be low. No relationship would be expected between the spatial temporal patterns of copper, with a correlation of 0.08 with the first component, and any of the above.

On the basis of the patterns in the factor loadings (correlation coefficients) on the first component, similar spatial temporal patterns would be exhibited by BOD, total solids, suspended solids, dissolved solids, COD, colour, conductivity, turbidity, total phosphorus, TKN, chloride, sodium, pH, temperature, dissolved oxygen, aluminum and hydrogen sulphide (Table 3). The first component accounts for more than 50% of the variance of each of these parameters.

Although some of the parameters with high correlations with the first component are commonly designated as conservative parameters (e.g. sodium) and others as non-conservative parameters (e.g. BOD) depending on their tendency to be broken down in time or space, their close relationship in this study suggests that there is little difference in their behaviour over the distance covered by the stations used in the analysis. Such a result would be obtained if dilution, rather than biodegradation, were the most important process governing the fate of non-conservative parameters over the distance examined. These results are confirmed by Johnson (1977) and Polak (1975a). Johnson observed that dilution along the plume centreline accounted for 98.5% of the losses of non-conservative parameters over a distance of 2 km from the outfall, while Polak developed linear functions to predict the concentration of both conservative and non-conservative parameters from conductivity measurements in the plume. This would not have been possible if conservative parameters behaved in a substantially different fashion than non-conservative parameters.

On the basis of the correlations between the original parameters and the station scores on the second component, copper and iron would be expected to exhibit similar spatial-temporal patterns. The second component accounts for more than 68% of the variance of both variables. Zinc is unique, with less than 35% of its variance being accounted for by either component. This indicates that its spatial-temporal pattern is different from those represented by the two principal components.

The spatial-temporal patterns of the parameters with high correlations with a particular component can be represented by the corresponding component scores of the sampling locations over the three days of sampling without a great loss of information when compared to an examination of each parameter separately. The station scores for a component are calculated from a linear combination of the parameters in the original data set and can be considered as an overall index of the concentration of those parameters highly correlated with the component. For example, the scores on the first component (Figures 8 to 10) are positive near the outfall indicating high levels of parameters such as BOD, total solids, etc., and low values of pH and dissolved oxygen. Conversely, stations with negative scores can be expected to have low levels of BOD and total solids, etc. and high values of pH and dissolved oxygen.

Temporally, the scores on the first component at individual stations vary somewhat, but the range of scores for each location included in the analysis was fairly narrow for the three days. This likely reflects the low variance in input of the associated parameters over the three days. A striking feature of the three plots is the rapid decrease in the scores of stations located approximately 400 m from the outfall and those located approximately 500 m from the outfall. This is indicative of a rapid change in parameter concentration over this distance. Minns (1977) similarly observed a rapid decline in the concentration of sodium, dissolved organic carbon, particulate organic carbon and particulate organic nitrogen in the immediate vicinity of the outfall.

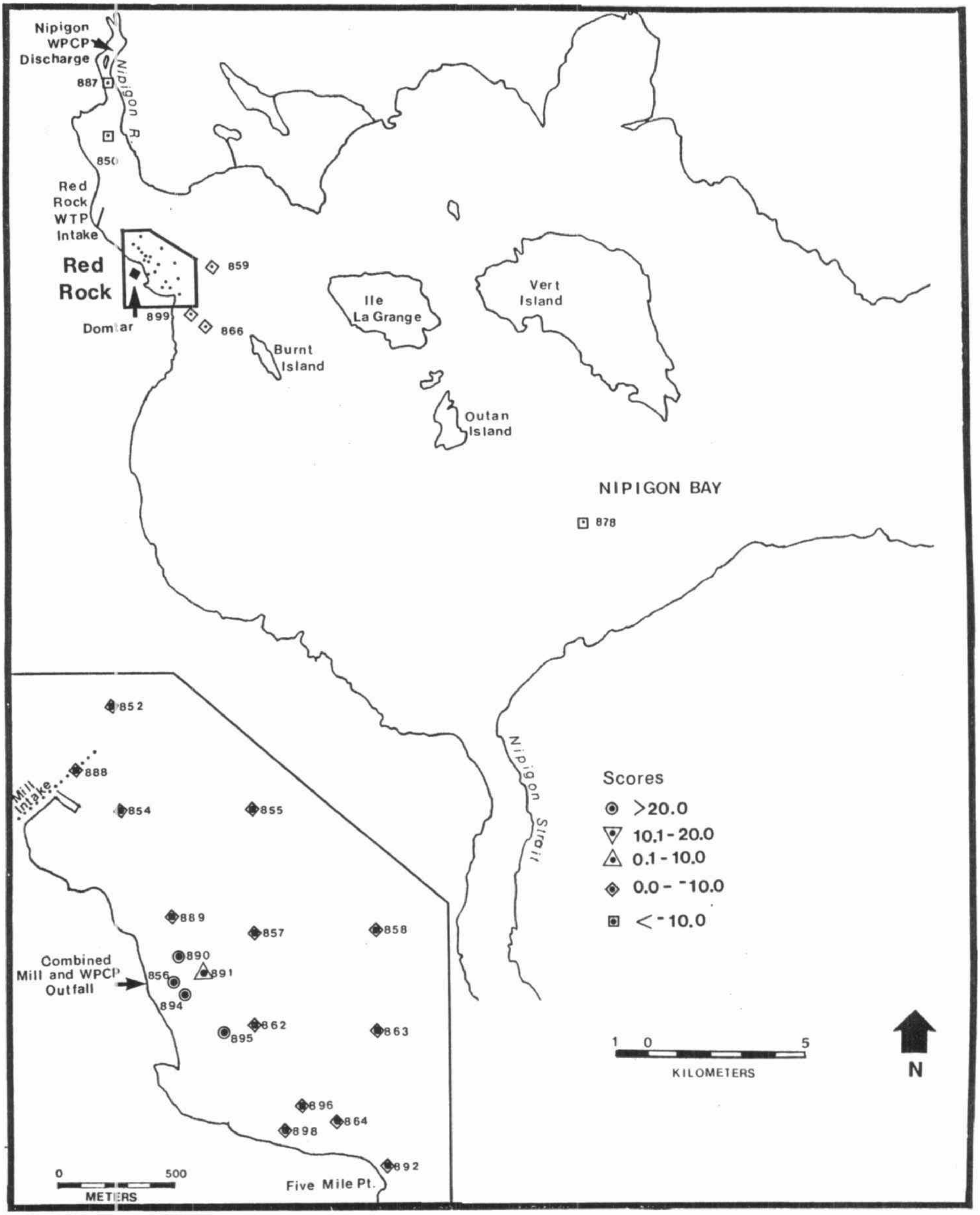


Figure 8. Station Scores on the First Principal Component for July 18,1983

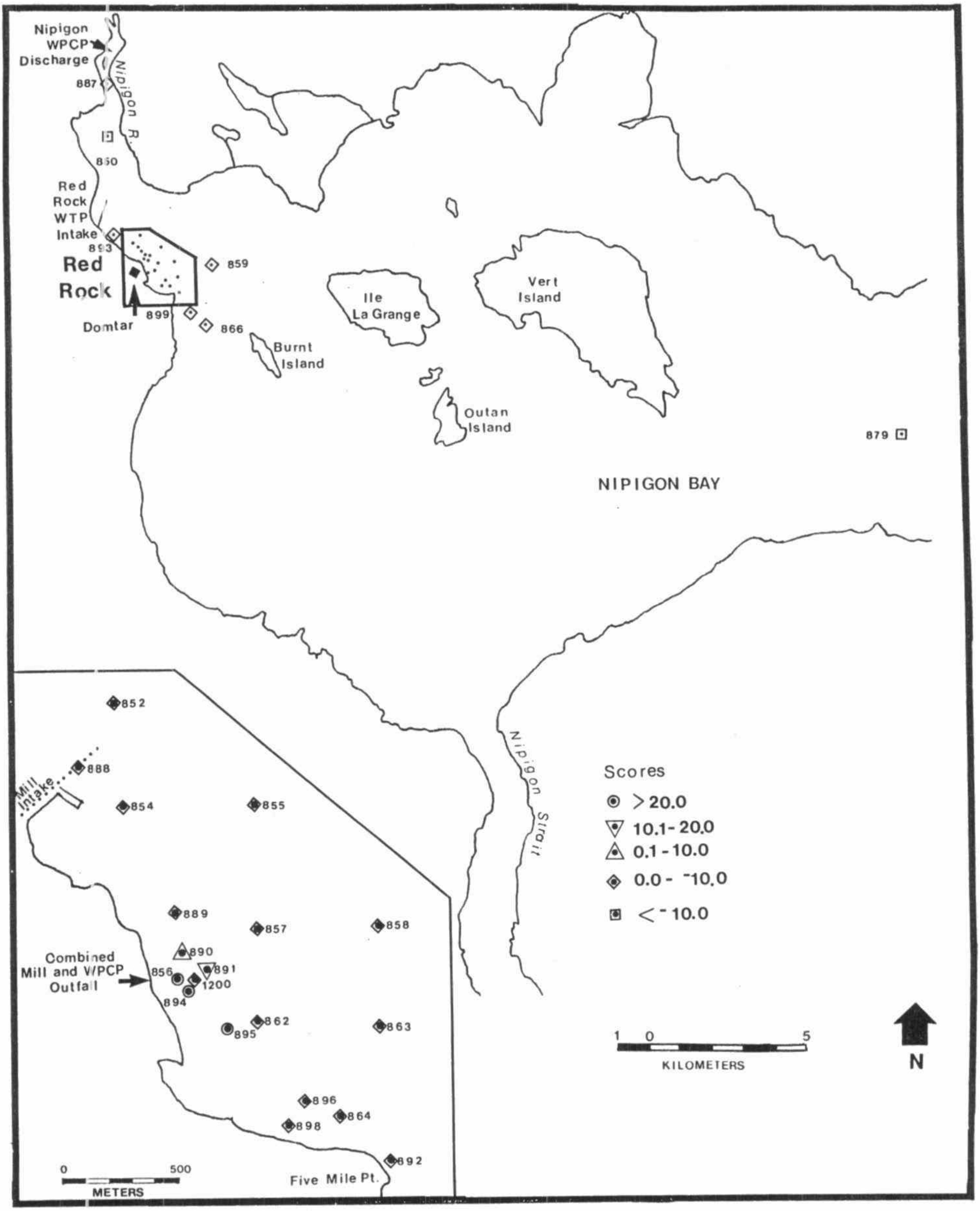


Figure 9. Station Scores on the First Principal Component for July 19,1983

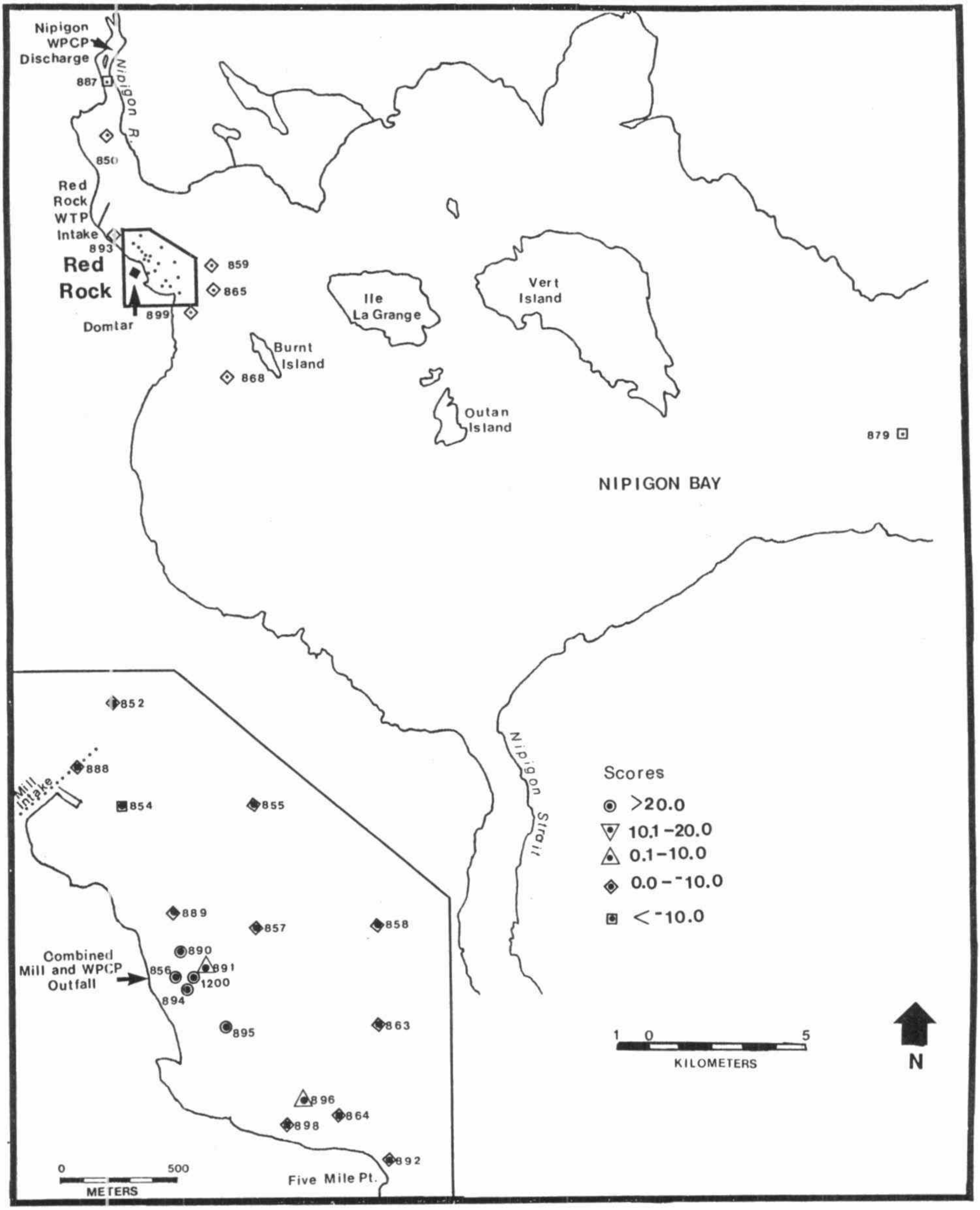


Figure 10. Station Scores on the first Principal Component for July 20,1983

The scores for the locations on the second component which are highly correlated with iron and copper levels have been presented in Figures 11 to 13. Overall, the patterns are less consistent from day to day and less interpretable than those apparent on the first component. Scores of locations near the outfall are positive on all three days, suggesting an association with the discharge. However, on two of those days the scores of stations in the east part of the bay outside the range of influence of the effluent were also positive. This is likely the result of the high background concentrations of copper measured in this area.

c) Comparison with 1974 Water Quality

The spatial and temporal patterns observed in 1983 could not be directly compared with those observed in 1974 due to substantial differences in study objectives and survey design. Although some water chemistry data were collected, the primary objective of the 1974 study was to define plume configuration on the basis of conductivity measurements (Polak 1975a). Sampling locations for water chemistry were situated between 190 m and 615 m from the outfall. These were not sampled in a systematic fashion on the five days of the survey which took place between July 4 and July 15. A comparison for overall differences between the two years was made using the Mann Whitney U Test.

The Mann Whitney U Test is a non-parametric test in which the "null hypothesis" is that there is no difference between the two years in the underlying population distributions of the parameters being tested. Included in the analysis were data collected in 1983 at stations within 190 m to 615 m of the outfall (854, 855, 857, 862, 889 and 895) and data collected in 1974 at the .2 m depth from the same area. Information was also available for 1974 on parameters concentrations at a 1.0 m depth, but these were not considered comparable to those collected in 1983, since the 1.0 m depth is at or near the boundary of the plume (Fox 1977). The results of the Mann

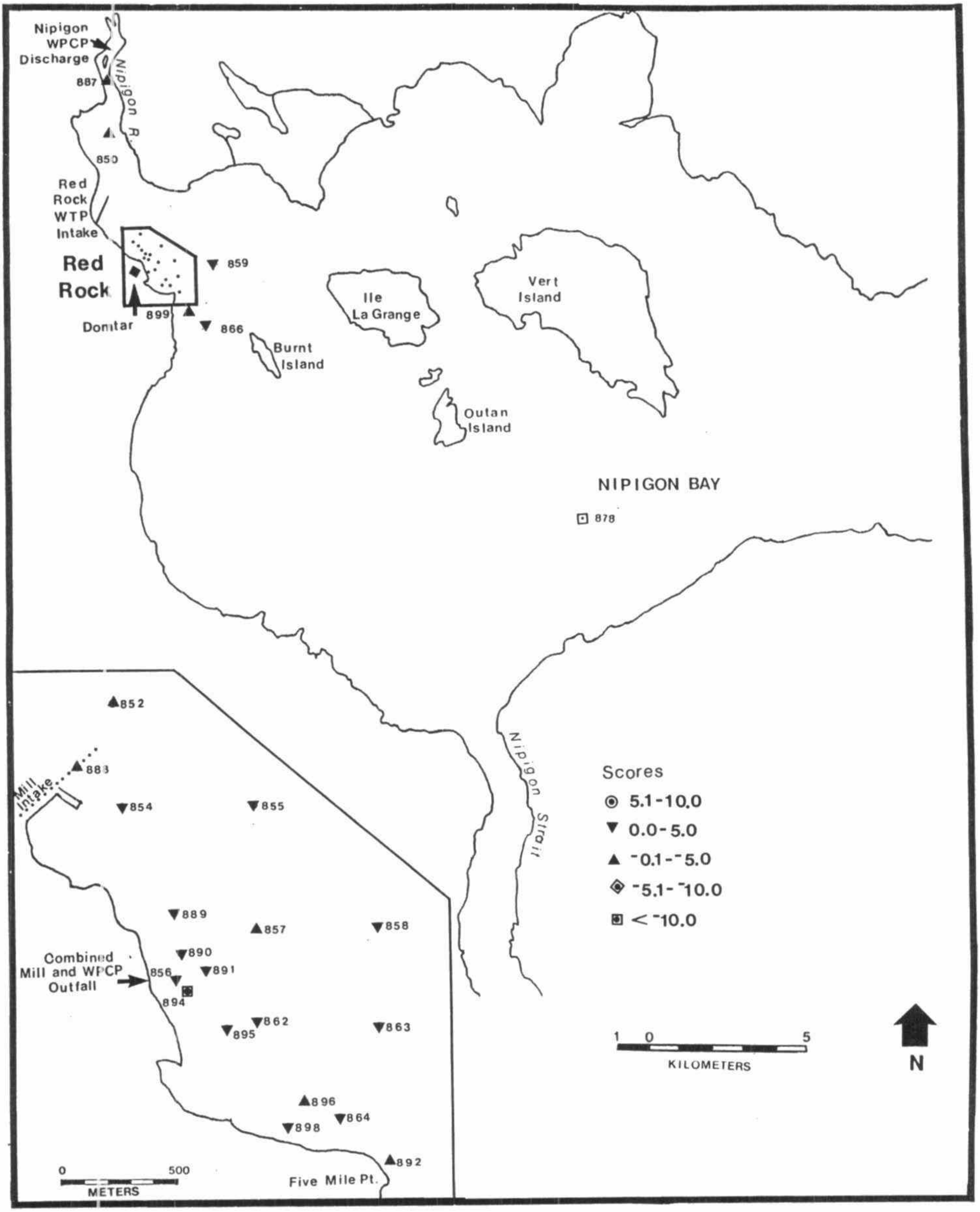


Figure 11. Station Scores on the Second Principal Component for July 18,1983

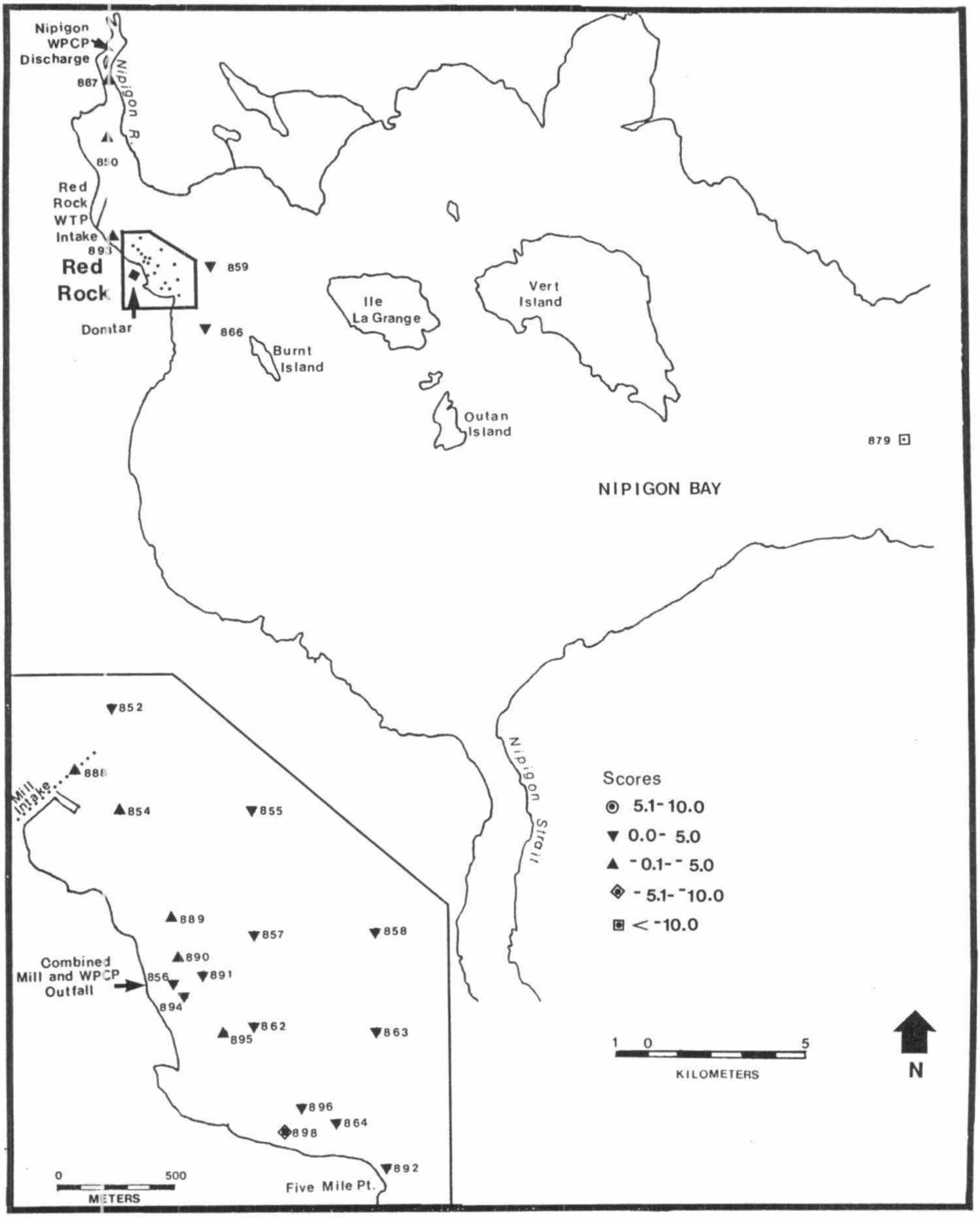


Figure 12. Station Scores on the Second Principal Component for July 19,1983

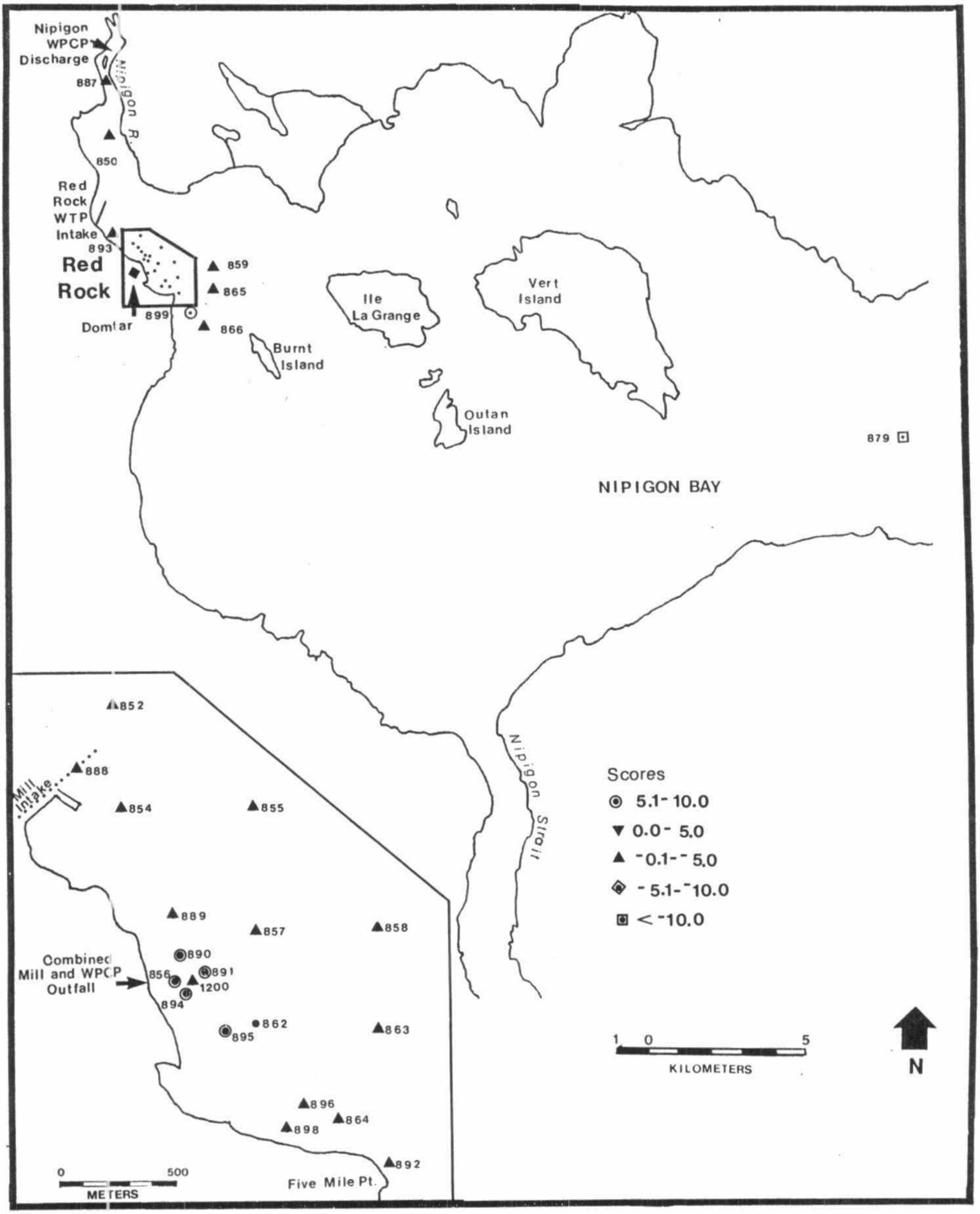


Figure 13. Station Scores on the Second Principal Component for July 20, 1983

TABLE 4

Comparison of the Water Quality in Nipigon Bay in 1974 with 1983

Parameter		1974	1983
Conductivity (us/cm)	g.m.	202.4	149.3
	r.	114-590	128-325
Chloride (mg/L)	g.m.	4.3	2.4
	r.	1-75	1.4- 23
Total Solids (mg/L)	g.m.	165.0	125.2
	r.	65-675	80-480
Dissolved Solids (mg/L)	g.m.	150.6	96.4
	r.	62-565	2-360
Suspended Solids (mg/L)	g.m.	11.4	4.8
	r.	2-155	1-120
Reactive Phenolics (ug/L)	g.m.	84.3	32.9
	r.	6-1125	1-5000
COD (mg/L)	g.m.	55.6	14.1
	r.	10-365	1-302
BOD (mg/L)	g.m.	12.4	2.1
	r.	0.8-150	0.7-37
Turbidity (FTU)	g.m.	8.1	3.7
	r.	0.7-83	2.1-42
Sodium (mg/L)	g.m.	13.7	4.0
	r.	2.2-110	1.4-44
Sulphate (mg/L)	g.m.	14.8	6.5
	r.	3.2-140	4-64
pH	m.	8.0	7.8
	r.	7.4-8.4	7.1-8.0

g.m. = geometric mean
m. = mean
r. = range

Whitney U Test indicate that there are significant differences between the two years for the conventional parameters listed in Table 4 except total solids, dissolved solids and pH ($p \leq .05$). The geometric mean concentrations for all parameters were lower in 1983 than in 1974, suggesting an overall improvement in water quality. The reduction in the geometric means is particularly significant since the locations included in the analysis were situated near the outfall in an area where the highest concentrations of many parameters were measured in the 1983 survey.

d) Bacteria

Violations of the Provincial Water Quality Objective for total coliforms (geometric mean of 1000 counts/100 ml) occurred in the immediate vicinity of the combined mill and WPCP outfall, at one station approximately 1 km from the Red Rock Water Treatment Plant and at a few locations near Five Mile Point and Ile La Grange (Figure 14). The mill is the main source of the total coliforms since the concentration of these bacteria in the combined effluent averaged eleven times that of the WPCP effluent for the period July 18-20, 1983. The highest concentrations of total coliforms in Nipigon Bay (Figure 14) were measured in the immediate vicinity of the combined mill and WPCP outfall with a rapid decline in numbers occurring at approximately 500 m from the outfall. There is some input of coliforms from the Nipigon River, where the Provincial Water Quality Objective was exceeded at station 887. Acceptable levels of total coliforms were measured downstream of this location at station 850.

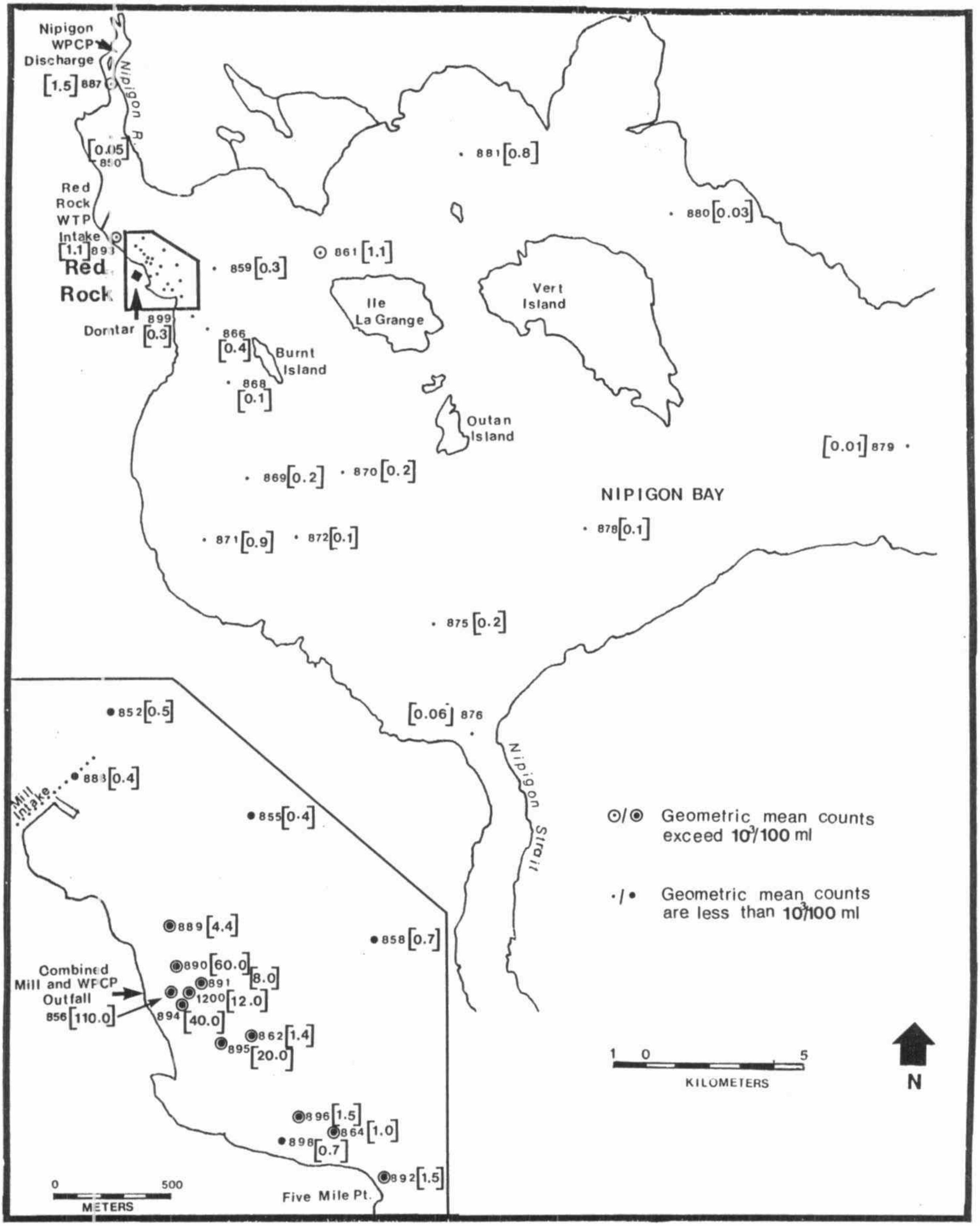


Figure 14. Distribution of Total Coliform Bacteria
Numbers in brackets are geometric mean counts $\times 10^3$/100ml

Fecal coliforms do not represent a significant portion of the total coliforms measured at most of the sampling locations in Nipigon Bay. The geometric mean counts/100 ml of fecal coliforms were less than 25 at all locations sampled, except two. These were station 856 near the combined outfall and station 862, 500 m away. Levels at these two locations (447 and 112 counts/100 ml, respectively) exceeded the Provincial Water Quality Objective of a geometric mean density of 100 counts/100 ml. In view of the generally low numbers of fecal coliforms and the absence of information concerning the species of bacteria detected by the total coliforms test, the potential health risks arising from recreational uses of Nipigon Bay cannot be assessed.

The distribution of heterotrophic bacteria exhibited a pattern similar to that of the total coliforms with the highest levels being measured at the combined mill and WPCP outfall and with the numbers declining rapidly a short distance away (Figure 15). Some input of coliforms comes from the Nipigon River with relatively high levels being detected at station 887 and with levels declining downstream. No Provincial Water Quality Objective exists for heterotrophs. The high numbers near the outfall are indicative of high concentrations of organic material.

e) Organic Compounds

The organic compounds detected and their ranges in concentration are presented in Table 5. Most of the compounds were restricted in distribution to within 600 m of the combined mill and WPCP outfall and most were detected at only a few locations. Exceptions to the general distribution pattern were the phenolic, vanillin; the fatty acids, myristic and palmitic; and the resin acids, pimaric and neoabietic. The distribution pattern for vanillin, with relatively high concentrations at station 850 in the Nipigon River (302 ug/L) and the low concentration at station 856 (near the outfall) and its vicinity, suggest the Nipigon River is the major source. The resin and fatty acids mentioned above occurred over a much broader range of locations than most other organics, but like them, reached their

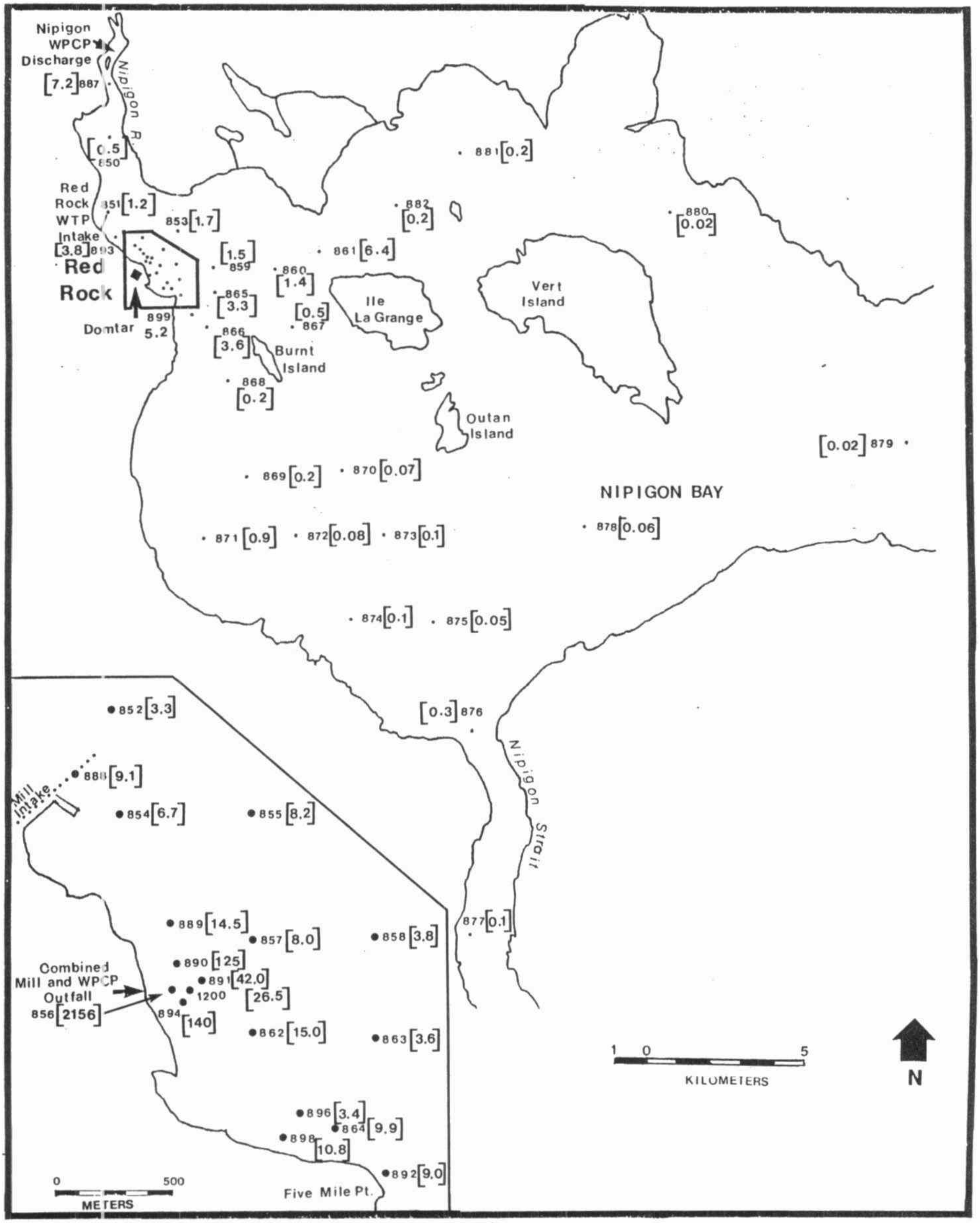


Figure 15. Distribution of Heterotrophic Bacteria
Numbers in brackets are geometric mean counts x10^4/ml

TABLE 5

RANGE IN CONCENTRATION OF THE ORGANIC COMPOUNDS DETECTED IN WATER SAMPLES COLLECTED AT VARIOUS LOCATIONS IN THE STUDY AREA

	Mill Intake	Combined Discharge	WPCP Discharge	NIPIGON BAY		NIPIGON RIVER	D/N[1]
				Station 856 Near Outfall	Other Stations		
Speciated Phenolics (ug/L)							
Vanillin	ND	13-44	ND	16	ND-288	302	7/23
Homovanillic acid	ND	ND	ND	ND	ND-540	ND	1/23
Guaiacol	ND	207-1120	ND	720	ND-576	ND	5/23
Acetovanillone	ND	6-75	ND	33	ND-171	94	8/23
Acetosyringone	ND	ND-19	ND	11	ND	ND	1/23
Organochlorine Pesticides and PCBs (ng/L)							
Polychlorinated biphenyls (total) (1 ng/L)[2]	ND	ND-65	ND	130	ND-950	ND	2/23
α Benzene hexachloride	1-5	ND- 9	ND	2	ND-5	3	18/23
γ Chlordane	ND-6	ND	ND	ND	ND	ND	0/23
Dieldrin (1 ng/L)[2]	ND-2	ND	ND	ND	ND	2	1/23
Endrin (2 ng/L)[2]	ND	ND	ND	ND	ND	8	1/23
pp DDD (3 ng/L total)[2]	ND	ND	ND	10	ND	ND	1/23
pp DDE	ND	ND- 2	ND	ND	ND	ND	0/23
Chlorophenols (ng/L)							
2,3,4-trichlorophenol (18,000 ng/L total)[2]	ND	ND	ND-200	ND	ND- 300	ND	2/24
2,4,6-trichlorophenol	ND-5100	200-6600	ND	160-340	ND-2100	ND	5/24
Pentachlorophenol (500 ng/L)[2]	ND	ND-760	250-700	ND	ND	ND	0/24
Fatty Acids (ug/L)							
Capric	ND-2	ND- 7	ND	3	ND-5	ND	4/19
Lauric	ND	ND-12	4	ND	ND-4	ND	1/19
Myristic	ND-1	5-11	56	2	ND-9	ND	7/19
Palmitic	1-12	17-106	357	7	ND-63	3	18/19
Stearic	ND-13	11-25	246	4	ND-20	ND	5/19
Oleic	ND-2	ND-64	253	14	ND-64	ND	5/19
Linololeic	ND-3	ND-137	180	18	ND-114	ND	4/19
Linolenic	ND	2-34	18	ND	ND-3	ND	3/19
Arachidic	ND	ND-16	ND	3	ND-6	ND	5/19
Aromatic Acids (ug/L)							
Benzoic	ND-11	ND-85	ND	ND	ND-4	ND	1/19
Salicylic	ND	22-50	ND	32	ND-31	ND	6/19
Phthalic	ND	ND-16	ND	ND	ND	ND	0/19
Resin Acids (ug/L)							
Pimaric	ND-5	93-199	18	21	ND-150	2	15/19
Sandaracopimaric	ND	43-135	3	15	ND- 73	2	8/19
Levopimaric	ND	ND-187	60	58	ND-121	ND	5/19
Isopimaric	ND-2	130-361	2	61	ND-213	ND	9/19
Neoabietic	ND-2	ND -<40	8	ND	ND-377	2	10/19
Abietic	ND-2	189-1800	18	59	ND-909	ND	5/19
Dehydroabietic	ND-2	273-681	20	79	ND-415	3	14/19
Organohalides (ug/L)							
Chloroform (1200 ug/L)[3]	ND-3	-	3-25	-	ND-10	5	4/12

[1] D/N - number of stations where a parameter was detected/number of stations where it was sampled.

[2] - Provincial Water Quality Objective

[3] - Interim Provincial Water Quality Objective

ND - not detected

- not sampled

highest concentrations at stations near the combined outfall. The occurrence of fatty and resin acids at great distances from the combined outfall is likely due to natural production and leaching from sunken logs (Fox 1977).

Of the organic compounds measured, the chlorophenols and speciated phenolics are important for assessing the violations of the Provincial Water Quality Objectives for reactive phenolics described earlier. Provincial Water Quality Objectives exist for two of the phenolics, namely; trichlorophenols (18 ug/L) and pentachlorophenol (.5 ug/L). Both compounds were present in the combined discharge, but neither objective was exceeded in the receiving water.

Of the remaining phenolics, guaiacol was detected above levels which taint fish flesh in laboratory studies (100 ug/L, Shumway and Palensky 1973) and cause odour problems in water (21 ug/L, Verschuren 1983, in de Barros 1984) in the combined WPCP and mill discharge, at station 856 near the outfall and at four other locations in Nipigon Bay within 700 m of the combined outfall (854, 890, 894 and 895). Guaiacol was not detected in the WPCP effluent alone, although concentrations ranged from 207 ug/L to 1200 ug/L in the combined effluent from July 17-20, 1983. This indicates the mill is the main source.

Other organics of concern are resin and fatty acids since they are the principal substances responsible for the toxicity of pulp and paper mill effluents to fish. Ninety-Six hour LC50 concentrations have not been established for all the resin and fatty acids listed in Table 5. However, isopimaric and abietic acids were detected in the combined mill and WPCP effluent at concentrations which are toxic to coho salmon (.22 mg/L and .41 mg/L (Tomlinson 1980), respectively), while abietic acid concentrations in the effluent exceeded the 96 hr LC50 concentration for trout (1.1 mg/L) (Tomlinson 1980). These results suggest that there is a potential problem with the toxicity of the combined effluent. Isopimaric and abietic acid were only measured once in both the combined mill and WPCP effluent and the WPCP effluent alone. The concentrations of isopimaric acid were 361 and 2 ug/L, respectively, in the combined and WPCP discharges, and of abietic acid, 1800 and 18 ug/L, respectively, suggesting the mill is the main source.

The toxicity studies conducted by Northwestern Region and the Toxicity Unit of the Ontario Ministry of the Environment included both in-situ and laboratory bioassays using fingerling rainbow trout (Flood et al draft). The laboratory bioassays were performed on effluent samples to determine whether or not the mill met with federal requirements for pulp and paper mill wastes of at least 80% fish survival in 65% effluent concentration at the end of a 96 hour exposure period (Environment Canada 1972). All, except one, of the six effluent samples met with federal requirements. Survival in the sample that failed was 70%. These results were not consistent with the results of the in-situ tests. One hundred percent mortality occurred at locations 100 metres north and south of the outfall, and 84% mortality occurred at Five Mile Point. The discrepancy between the two sets of results could have arisen due to differences in experimental conditions. Temperature in Nipigon Bay did not exceed the Provincial Water Quality Objective, but could have contributed to the mortality in the in-situ studies, since the trout were acclimated to low temperatures prior to the study and may have experienced thermal shock when placed in Nipigon Bay. Additional stresses may have also arisen from low concentrations of dissolved oxygen and high concentrations of hydrogen sulphide. None of these stresses were present in the laboratory experiments which were aerated and temperature controlled.

The organochlorine pesticides and polychlorinated biphenyls are ecologically important because they are toxic and can be bioaccumulated in the food chain. Several of these types of compounds were detected in Nipigon Bay, but generally at only a few sampling stations (Table 5). PCBs were detected at two locations in the receiving water (station 856 near the outfall and station 895 about 300 m away) and concentrations at both stations exceeded the Provincial Water Quality Objective of 1 ng/L. Since PCBs were also detected in the combined mill and WPCP effluent, but not in the WPCP effluent alone, it is likely that the mill is the source.

Endrin exceeded the Provincial Water Quality Objective at station 887 on the Nipigon River. Dieldrin also exceeded the Provincial Water Quality Objective at this location, as well as at the mill intake. Neither endrin nor dieldrin were detected at the outfall, in the combined dishcarge or in the WPCP discharge, leaving the source unknown.

A metabolite of DDT, ppDDD, was detected at station 856 near the outfall above the 3 ng/L Water Quality Objective for DDT and its metabolites. The source is unknown since it was not detected in either the combined mill and WPCP discharge or the WPCP discharge.

In 1974, over 90 organic compounds were observed in the mill effluent and the effluent plume, of which 36 were identified (Fox 1977). The analyses in 1984 included only 12 of the organics identified in 1974 (Table 6). Due to the semi-quantitative nature of the 1974 results and the limited overlap of the organic compounds analyzed in the two years, it is difficult to determine whether or not any change has occurred.

TABLE 6

Organic Compounds Identified in the Combined
Mill and WPCP Effluent
and Effluent Plume in 1974 and 1983.
Major Components > 100 ug/L, Minor Components < 100 ug/L

+ - in Effluent in 1975
* - in Effluent in 1983

Compound	Major Component	Minor Component	Detected in Effluent Plume
Guaiacol	+*		+*
Acetovanillone	+	*	+*
Myristic acid		+*	+*
Palmitic acid	+*		+*
Stearic acid	+*		+
Arachidic acid	+	*	+*
Oleic acid	+*		+*
Linoleic acid	+*		+*
Isopimaric acid	+*		+*
Sandaracopimaric acid	*	+	+*
Dehydroabietic acid	+*		+*
Abietic acid	+*		+*

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APPENDIX 1

PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS INCLUDED IN THE ANALYSES OF THE WATER SAMPLES FROM NIPIGON BAY - 1983

- Dissolved Organic Carbon (DOC)
- Tannins
- Sulphate
- Reactive Phenolics
- Biochemical Oxygen Demand (BOD_5)
- Total Solids
- Suspended Solids
- Dissolved Solids
- Chemical Oxygen Demand (COD)
- Colour
- Conductivity
- Turbidity
- Total Phosphorus (TP)
- Total Kjeldahl Nitrogen (TKN)
- Chloride
- Sodium
- pH
- Ammonia
- Water Temperature
- Dissolved Oxygen

Trace Metals and Toxic Substances

- Mercury
- Aluminum
- Arsenic
- Cadmium
- Cobalt
- Chromium
- Copper
- Iron
- Nickel
- Lead
- Zinc
- Hydrogen Sulphide
- Cyanide

Bacteria

- Total Coliforms
- Fecal Coliforms
- Fecal Streptococci
- Heterotrophs
- Pseudomonas Aeruginosa
- Escherichia Coli
- Sulphate Reducers

Phenolic Compounds

- Phenol
- Vanillin
- Homovanillic Acid
- Guaiacol
- Syringaldehyde
- Acetovanillone
- Vanillic Acid
- Acetosyringone
- 2,5 xylenol
- p-cresol
- m-chloro-p-cresol
- 2-chlorophenol
- 4-chlorophenol
- 2,4-dichlorophenol
- 2,3,4-trichlorophenol
- 2,4,5-trichlorophenol
- 2,4,6-trichlorophenol
- 2,3,4,5-tetrachlorophenol
- 2,3,5,6-tetrachlorophenol
- 2,4,5,6-tetrachlorophenol
- pentachlorophenol
- Fatty Acids
- Capric
- Lauric
- Myristic
- Palmitic
- Stearic
- Oleic
- Linoleic
- Linolenic
- Arachidic

Aromatic Acids

- Benzoic
- Salicylic
- Phthalic

Resin Acids

- Pimaric
- Sandaracopimaric
- Levopimaric
- Isopimaric
- Neoabietic
- Abietic
- Dehydroabietic

APPENDIX 1 (cont'd)

Organohalides

- Chloroform
- Carbon tetrachloride
- Trichloroethylene
- Dichlorobromoethane
- Chlorodibromomethane
- Tetrachloroethylene

Polychlorinated Biphenyls (PCB's) and Organochlorine Pesticides

- PCB's total
- Aldrin
- α benzene hexachloride (BHC)
- β BHC
- γ BHC (lindane)
- α chlordane
- Dieldrin
- DMDT-methoxychlor
- Endosulphan 1
- Endosulphan 2
- Endrin
- Endosulphan sulphate
- Heptachlor epoxide
- Heptachlor
- Mirex
- Oxychlordane
- o,p-DDT
- p,p-DDD
- p,p-DDE
- p,p-DDT
- Hexachlorobenzene

Fatty acids

- Capric
- Lauric
- Myristic

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